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Post Office Engineering Department

TECHNICAL PAMPHLETS FOR WORKMEN

Subject

Elementary Principles of Telephony

ENGINEER-IN-CHIEF'S OFFICE
1919

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ELEMENTARY PRINCIPLES OF TELEPHONY

(**D 1**)

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A1 Magnetism and Electricity.

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A5 Protective Fittings.

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ELEMENTARY PRINCIPLES OF TELEPHONY

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ELEMENTARY PRINCIPLES OF TELEPHONY

ACOUSTICS

Sounds are caused by vibration of the sounding bodies. If a tuning-fork be struck it can be seen that its prongs are in a state of rapid vibration. The movement of the prongs sets up vibrations in the air in the immediate neighbourhood. These vibrations travel outwards at the rate of 1,120 ft. per second, and they produce in the ear the sensation which we recognize as *sound*. Sound travels by a "to-and-fro" or *wave* motion of the particles of air, and not by a bodily movement of the air from one place to another. An illustration of wave motion is provided when wind passes over a cornfield. Waves appear to travel continuously over the cornfield, but the illusion of forward motion is created simply by the rise and fall of the heads of corn swinging in the wind.

Sound waves actually consist of alternate compressions and rarefactions of the air, and audible sound waves vary from 0·7 of an inch to approximately 70 feet in length.

Sound waves differ from each other in three particulars—in *pitch*, in *volume* and in *timbre* or quality. The **pitch** of a sound is determined by the rapidity of the vibrations. The **volume** is determined by the energy in the vibrations, which is proportional to the square of the amplitude. Sounds of equal pitch and loudness differ from each other in **quality**—for example, the note of a flute differs in quality from that of a violin, this being due to differences in the relative frequencies, amplitudes, or phases of the overtones present in the two cases.

To transmit speech from one place to another, other than directly through air or similar sound-conducting substance, we may employ a contrivance consisting of:—

(a) An instrument which is actuated by the sound waves and converts the energy of these into the energy of vibrations of a different form, or which, when actuated by the sound waves, brings into use energy from another source.

(b) A medium in conjunction with the above instrument along which the converted energy, or the energy brought into use, can travel.

(c) A second instrument which reconverts the transmitted energy into sound waves similar to those originally produced.

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The simplest form of the contrivance referred to in the foregoing paragraphs is illustrated in Fig. 1. It consists of a couple of tin cylinders. Across one end of each cylinder is stretched a flexible diaphragm, the centres being connected by a stretched string. In this case speech is transmitted from one diaphragm to the other by mechanical vibrations in the string.

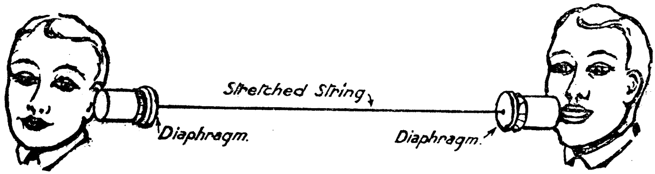

Fig. 1.

In an electric telephone speech is transmitted by means of electrical current, and the simplest way in which this can be done is by the use of two telephone receivers connected through a line circuit.

ELECTRICAL TRANSMISSION OF SPEECH

A telephone receiver consists of a permanent horseshoe magnet with soft iron pole-pieces, on which are wound coils of insulated copper wire. In front of these pole-pieces is placed a soft iron (or ferro-type) diaphragm, as indicated in Fig. 2. Some of the magnetic lines of force pass from one pole-piece *through the diaphragm* to the other pole-piece. Some, however, take a direct path *through the air space* between the pole-pieces. If a sound wave causes the diaphragm to move *inwards* towards the pole-pieces, some of the lines of force which passed directly between the pole-pieces will now pass through the diaphragm. Similarly,

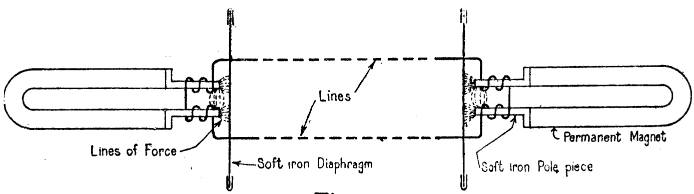

Fig. 2.

if the diaphragm moves ***outwards***, some of the lines of force, which normally pass through the diaphragm in a position of rest, will pass through the air. The result of these movements of the diaphragm in the magnetic field is that the lines of force are redistributed. Whenever a change occurs in the distribution of lines of magnetic force cutting a conductor an E.M.F. is induced in that conductor, and if the circuit is closed a current

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flows. Consequently currents varying precisely with the movements of the diaphragm are set up in the transmitting receiver circuit. These currents passing through the connecting line set up variations in the magnetic field of a similar receiver at the other end of the line, and reproduced motions of the diaphragm like those set up in the transmitting receiver by the sound waves.

The movement of the diaphragm in the transmitting instrument is produced by the energy of the sound waves, and there is considerable loss when this sound energy is converted into electrical energy, transmitted over a line, and finally changed from electrical energy into the resulting sound waves. This method of transmission by means of two receivers can be used over very short distances only, owing to the weakness of the telephone receiver as a " transmitter," and to the consequent smallness of the received sound.

In practice telephone *receivers,* as the name implies, are used only for receiving speech, and *transmitters* of a more sensitive and efficient type are used for speaking purposes.

Permanent magnets are essential in the design of receivers. The varying magnetic field of a receiver due to the varying received speech currents only would be comparatively small. The strength of the magnetic field of the permanent magnet is many times greater than that produced by received speech current and consequently the effects of the combined fields are increased accordingly.

Also the permanent magnet prevents sound being reproduced at double the frequency. Without a permanent magnet, the receiver diaphragm would be attracted once for each half cycle of received current. Thus a transmitted note having a frequency of 250 cycles would be received as a 500-cycle note, *i.e.,* one octave higher.

PRACTICAL RECEIVERS

In some of the earlier forms of receiver, in which the permanent magnet was fixed to the end of an ebonite case, variations in receiver-speech occurred in hot and cold weather owing to the expansion or contraction of the magnet causing variations in the distance between the magnet and the diaphragm.

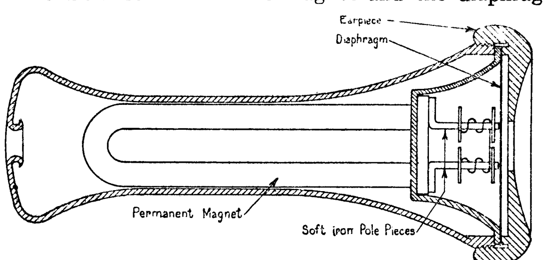

Fig. 8.

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The receiver used in connexion with the Common Battery telephone system (Fig. 3), is contained in a brass case coated with ebonite and furnished with an ear cap which clamps the diaphragm round its edges. The magnet and pole-pieces are fixed to a small dish-shaped bowl, which in turn, is clamped beneath the ear-piece. The outer ends of the pole-pieces and the diaphragm move practically together, with the alterations in length of the brass case of the receiver due to changes of temperature; consequently, variations in the distance between them is reduced to a minimum. The resistance of the coils is 60^w.

Another type of receiver which is used on micro-telephones and on operators' headgear apparatus is illustrated in Fig. 4. The magnet is circular in form, and has "consequent poles." This term indicates that a bar or ring is so magnetised that similar poles meet at a point or points in the magnet. In the case of the ring magnet of the receiver, similar poles come together at two points which are at the opposite ends of a diameter of the ring as shown in Fig. 4. *The ring is thus equivalent to two horseshoe magnets with similar poles placed together,* the junction of each pair of similar poles being furnished with a soft iron pole-piece on which a coil of wire is wound.

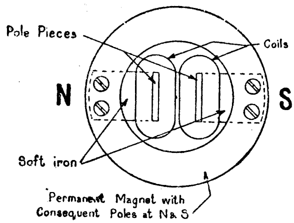

Fig. 4.

The inset receiver used on the latest type of microtelephone is illustrated in Fig. 5. It contains a permanent bar-magnet of cobalt steel, upon which two L-shaped

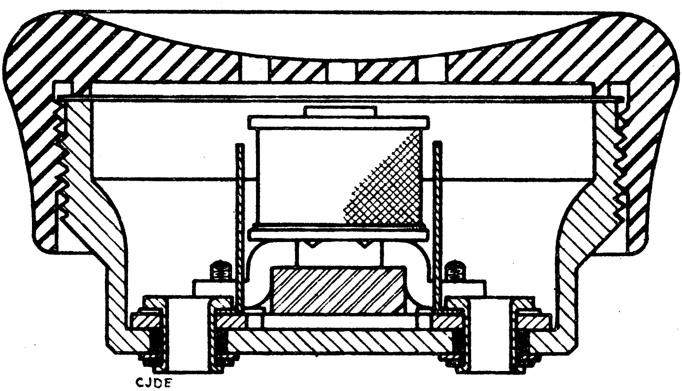

Fig. 5.—Inset Receiver (as used on microtelephone).

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polepieces are clamped. The coils are wound for a resistance of 80 Ω. Connexion to the receiver coils is made by two screws, which also serve to clamp the receiver to the handle of the microtelephone.

For diaphragms the new magnetic alloy known as "stalloy" (a mixture of silicon, aluminium and iron) is now extensively employed instead of soft iron. The magnetic properties of this alloy are equal to those of soft iron, but its "specific resistance" is very high, which reduces the "eddy" currents induced in it when moving in a magnetic field, and thus also reduces the amount of energy wasted. Hence a receiver with a stalloy diaphragm gives somewhat louder received speech than one fitted with a soft iron diaphragm.

TRANSMITTERS

Practical telephone transmitters are all of the carbon granule type. One type of inset transmitter still in use, but gradually being replaced by the standard inset, illustrated in Fig. 9, is made in the form of an air-tight nickel-plated brass capsule (*see* Fig. 6). It contains a round, grooved carbon block with carbon granules held between the block and the carbon diaphragm by a couple of turns of flannel surrounding the carbon block and glued to the diaphragm. A small disc of frayed flannel is fixed in the centre of the diaphragm. Movement of the carbon diaphragm *inwards* presses the granules together and the *resistance* between the carbon diaphragm and the carbon electrode is *reduced*. When the diaphragm moves *outwards* the pressure on the granules is reduced, and the *resistance increases*. This effect is due to changes in the area of contact between the granules, and may be illustrated by considering two spheres placed against each other (Fig. 7).

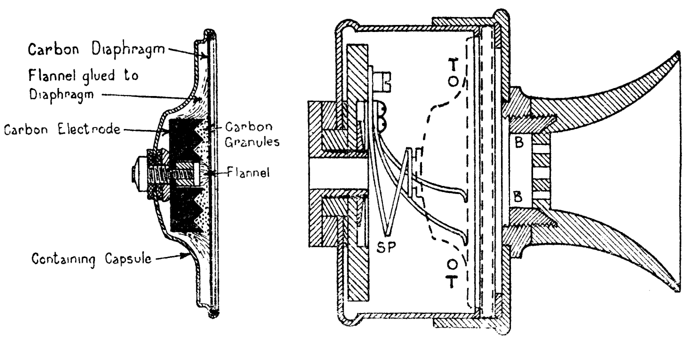

Fig. 6.—Inset Transmitter.

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When the spheres are just touching each other the area of contact is a mere point, whereas, if they are pressed together firmly, both spheres are slightly flattened at the surface of contact, and instead of a *point*, a *circular area* of some extent is created. The resistance between the two spheres will, therefore, vary from a maximum when they are just touching to a minimum when they are heavily pressed together. Movement is greatest at the centre of the diaphragm, and least at the circumference where it is clamped. The granules are, therefore, placed at the centre of the diaphragm so that movements due to sound waves may

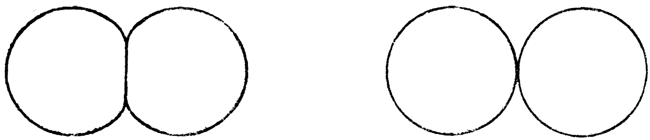

Fig. 7.

produce large changes in resistance. A corrugated form of carbon electrode is adopted to prevent the granules from becoming "packed"; because, in this condition, little variation of resistance would occur with movement of the diaphragm, and the instrument would become inefficient. If the back electrode were equal in diameter to the diaphragm, and the space between them *filled* with granules, there would have been an unvarying resistance between the outer or more or less immovable parts of the diaphragm and the carbon electrode. This would resemble, in effect, a "shunt" across the transmitter, and would very greatly reduce its efficiency.

The "solid-back" transmitter is illustrated in Fig. 8. This transmitter was the standard type for many years but it is now being superseded by the inset transmitter. The small brass cell is paper-lined, and contains very fine carbon granules placed between the back and front carbon electrodes, which are of less diameter than the chamber. The front electrode is carried on a thin mica disc, and the centre of this carbon block is rigidly attached to the *aluminium* diaphragm. The front electrode moves bodily with the movements of the centre of the diaphragm, where the maximum motion due to sound waves occurs. The diaphragm is mounted with rubber around its edge, and two rubber-tipped springs also bear upon it in order to deaden or "damp out" persistent vibration, and thus to ensure that the movements of the diaphragm answer to the sound waves as closely as possible. This point can, perhaps, best be illustrated by considering the behaviour of a tuning-fork. The tuning-fork, having been struck, continues

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to vibrate long afterwards. A telephone diaphragm which had similar properties would seriously distort speech, since the effects of one set of waves would not have died out before another set impinged upon it. Moreover, sounds which happened to have the same rate of vibration as the natural rate of the diaphragm would be unduly loud as compared with sounds of a different pitch.

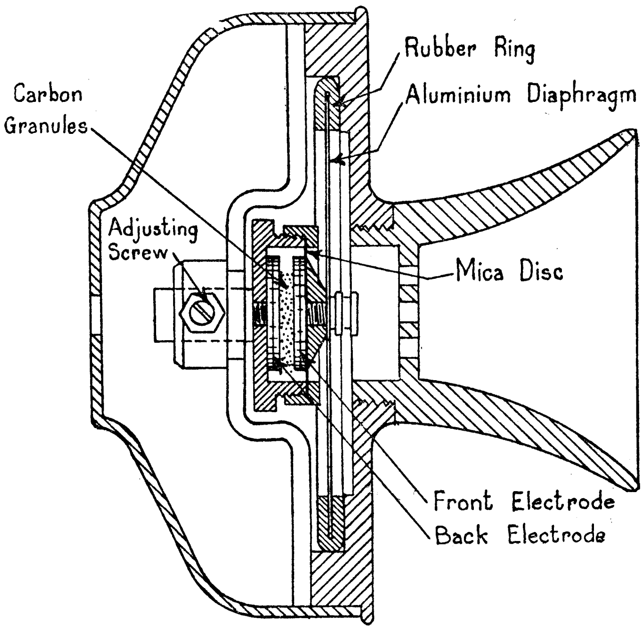

Fig. 8.—Solid Back Transmitter.

The standard transmitter used in the latest type of micro-telephone is illustrated in Fig. 9. It has a single corrugated aluminium cone diaphragm, having a small aluminium cylinder fixed to its centre. This cylinder projects into the granule chamber and carries the moving carbon electrode. The other carbon electrode is fixed to the base of the transmitter case, the faces of the two electrodes being 75-81 mils apart at about the centre of the granule chamber. Rings of silk, forming a sliding fit on the cylinder attached to the diaphragm, are clamped in the granule chamber to prevent leakage of the granules. With this arrangement, the electrodes are almost completely immersed in granules in whatever position the transmitter may be held.

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If a carbon transmitter, a battery, and a receiver be connected to transmit speech, the energy for operating the receiver is furnished by the battery. The action of the sound wave on the carbon transmitter is merely to move the diaphragm, whereas a receiver used as a transmitter may be regarded as a form of dynamo driven by the energy of the sound waves. It will, therefore, be appreciated that very much louder received sounds can be obtained by using a carbon granule transmitter. There is, however, unfortunately, a definite limit to the battery power which can be employed. If this exceeds a certain critical value the transmitter begins to hiss, and speech becomes impossible owing to heating at the points of contact between the granules. This critical value is reached when the tension applied directly across the transmitter is between 3 and 4 volts for the inset type and about 12 volts for the solid back type.

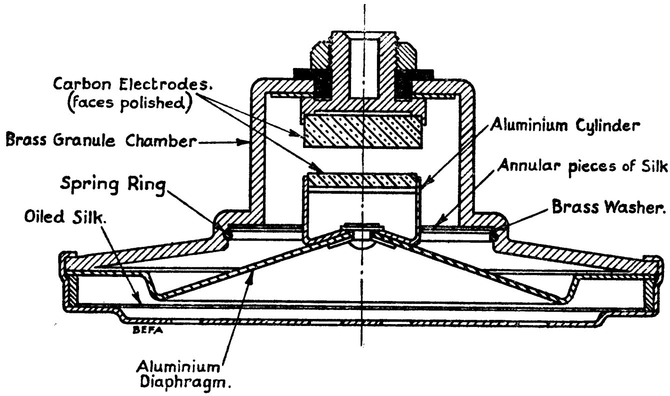

Fig. 9.—Transmitter, Inset No. 10.

There is a tendency for the granules in transmitters to bind together under certain conditions. This is known as " packing " and is more prevalent in the inset type of transmitter. Packing is also associated with the " breathing " effect in microphones, which is due to alternate heating and cooling when switching on and off the feeding current, and to barometric changes operating upon the diaphragm from the exterior. To counteract the latter action, a breathing hole of 15 mils diameter is drilled in the outer container of inset transmitters. The hole is sufficient for the purpose and is minute enough to exclude impurities from the air.

Contact is made by a plug and socket for one connexion, and by springs making contact with the transmitter case, for the other.

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INDUCTION COIL

If a particular sound wave causes an alteration of 1ω in the resistance of a transmitter, and the resistance of the transmitter, battery, lines, and receiver amounts to, say, 100Ω, the effect on the receiver is due to 1 per cent. variation in the current. If, however, the resistance of the circuit amounted to 1,000Ω, the current variation would amount only to one-tenth of 1 per cent., *i.e.*, the received speech would

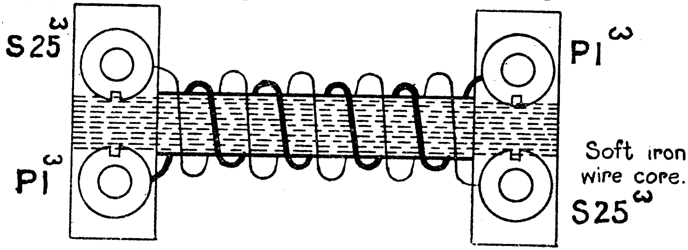

Fig. 10.

be of one-tenth the volume only. In other words, the variations in the resistance of the transmitter would be swamped by the large unvarying resistance added to it.

Induction coils are used with primary battery telephones to eliminate the effect of large external resistances, and also to ensure the maximum variations of resistance in the "speaking circuit." The arrangement consists of a bundle of fine iron wires, over which two coils of wire are wound (Fig. 10). The first, or *primary coil*, is wound to a resistance of 1Ω, whilst the *secondary coil* is wound to a resistance of 25Ω. The transmitter circuit, the resistance of which varies with the vibrations of the diaphragm of the transmitter, consists only of the transmitter itself, the primary winding of the induction coil, the battery (with, of course, a switching device and the wires connecting these together). The resistance of this circuit is low, and is independent of the resistance of the external line circuit.

When a magnetic field threading a conductor or system of conductors (such as a coil of wire) is so altered that the number of lines of force threading the windings is increased or decreased an E.M.F. is induced in the windings. Thus, a bar magnet plunged into a coil of wire produces this effect; and when the magnet is withdrawn, an E.M.F. in the *opposite* direction is produced. If an electromagnet, consisting of a bar of soft iron wound with a number of turns of insulated wire, be placed within the coil instead of the bar magnet, the starting and stopping of a current through the electromagnet will produce similar effects to those produced by the insertion and withdrawal

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of the bar magnet. Variations in the current in the primary circuit, *i.e.*, in the circuit of the electromagnet, will produce similar and corresponding E.M.F.'s in the surrounding coil or secondary winding. An increase in the current, increasing the number of lines of force threading the coil, will produce a proportionate E.M.F. in one direction, whilst decreasing the number of lines of force threading the coil will produce an E.M.F. in the opposite direction. It is important to remember that the induced E.M.F. in the secondary coil does not merely vary in strength with the number of lines of force issuing from the primary coil. An *increasing* magnetic field induces a secondary E.M.F. in one direction; a *decreasing* field induces an effect entirely opposite in direction; whilst a perfectly *steady* magnetic field induces no E.M.F. whatever in the secondary circuit.

The primary coil is wound upon a bundle of fine iron wires instead of upon a solid iron core, in order to prevent loss of energy through the core itself acting as a secondary circuit.

The E.M.F. induced in the secondary coil is greater than the E.M.F. applied to the primary coil, as the number of turns in the secondary coil is greater than the number of turns in the primary coil. Hence, if 2 volts be applied to a primary coil of 100 turns, an E.M.F. of 200 volts will be induced if the secondary turns number 10,000. The *current* in the secondary coil will, however, be very much smaller than that in the primary, since the power in the secondary is equal to the power in the primary (product of the E.M.F. and current), less internal losses in the arrangement.

The secondary winding is of comparatively high resistance in order that it may contain a comparatively large number of turns of wire and thus provide a relatively high E.M.F. for transmission over the circuit.

The transmitter, battery, and primary of the induction coil are joined in series. If the total resistance of this circuit amounts to $20\,\Omega$, a $1\,\Omega$ variation in the resistance of the transmitter produces a variation of 5 per cent. in the current flowing through the primary circuit. These variations induce similarly varying secondary currents, which pass along the lines, through the distant secondary and receiver, back to the transmitting station. The induction coil necessarily entails a loss of energy in transformation, but this is of small consequence in comparison with the improved overall efficiency of the transmitter system.

Since the current through the primary circuit is always in the same direction, and comparatively large, it is essential that an *open magnetic circuit*, *i.e.*, a magnetic circuit in which air is a portion of the path of the magnetic flux and definite poles are formed, must be employed. Demagnetization on cessation of the current is due to the action of the poles through the core.

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With alternating currents a closed ring of iron on which the coils are wound would suffice, since demagnetization would be effected at each reversal of the current.

MAGNETO STATION

In order to employ the transmitter, receiver, and induction coil for practical purposes, two requirements must be met. Firstly, a method of signalling between the two stations to attract attention, and secondly, a method of disconnecting the transmitter battery when the apparatus is not in use, so as to prevent waste of energy. Signalling can be provided by means of batteries, switches, and a trembler bell; but generally, a magneto generator and a magneto bell are employed. In the old type microtelephone, a lever in the handle of the instrument is employed to complete the circuit of the transmitter, and this lever is kept depressed during speech. In the pedestal pattern and the later pattern microtelephone, the closing of the transmitter circuit is effected by the gravity switch, when this is released by the removal of the receiver.

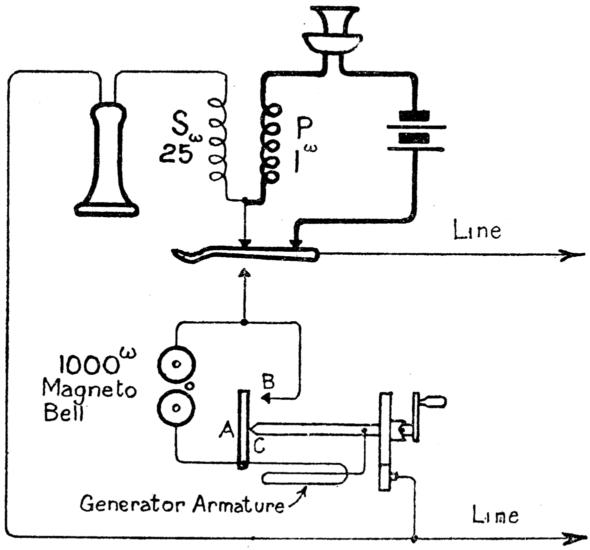

Fig. 11.

The change over from signalling to speaking conditions is brought about by the gravity switch. The receiver, or micro-telephone, normally depresses this switch against the tension of a spring, and in this position the signalling apparatus is connected. The removal of the receiver or telephone releases the switch and establishes speaking conditions (Fig 11).

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The magneto generator usually consists of three permanent magnets furnished with soft iron pole-pieces, between which a Siemens " H " armature wound with fine copper wire is revolved. From Fig. 12 it will be observed that in the first position the whole of the lines of force pass through the web, whilst in the second position they pass through the ends of the armature. These changes in the magnetic field threading the coil produce an alternating current, which is used to ring the distant bell. The generator (see Fig. 11) is provided with a switch, which is operated when the handle is revolved. In the normal position the connections indicated are formed, but before the armature of the generator can revolve the handle slides outward, and this causes the spring *A* to break with *C* and to make contact with *B*.

The object of this device is to disconnect the coil of the generator for received rings, and to cut out the bell when originating a call.

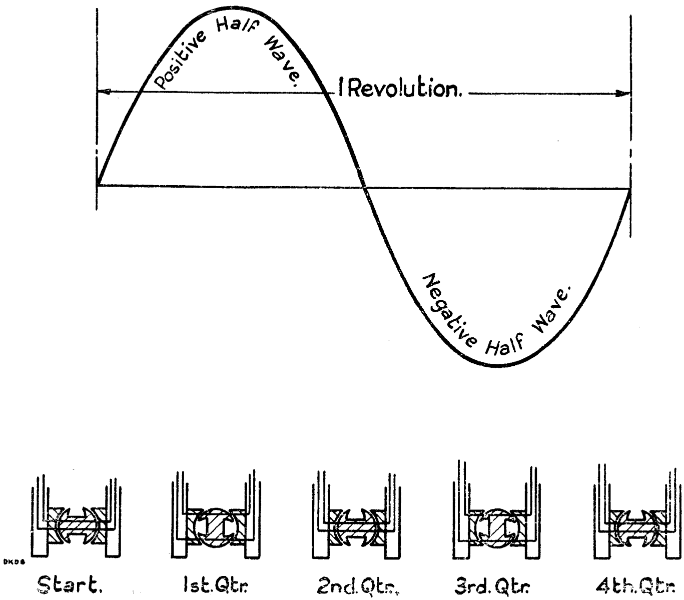

Fig. 12.

With the advent of automatic telephone systems, it has become necessary to provide through-clearing facilities to such exchanges under certain conditions on junction calls. To provide this facility, *i.e.*, a disconnexion when the receiver is on the gravity switch, a condenser is connected in series with the

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magneto bell, thus alternating current for ringing the bell can flow, but direct current cannot flow until the receiver is removed from the gravity switch. A magneto system providing these facilities is said to be " condensered ".

The magneto bell (Fig. 13) consists of a horseshoe electromagnet with a pivoted soft iron armature both of which are magnetised by the large U-shaped magnet having one pole over the centre of the yoke of the electromagnet and the other over the centre of the armature. The magnet induces similar polarity in each end of the armature and similar, but opposite polarity to that of the armature, in each of the poles of the electromagnet. Current through the coils of the polarized electromagnet (which are wound in opposite directions) strengthens the magnetism in one pole and weakens that in the other. One end of the armature is therefore attracted. Reversal of the current reverses these conditions and the other end of the armature is then attracted. Attached to this armature is a striker which plays between the two bell gongs.

It is important to distinguish between the *primary, secondary,* and *signalling* circuits. The **primary circuit** comprises the battery, the transmitter, the primary winding of the

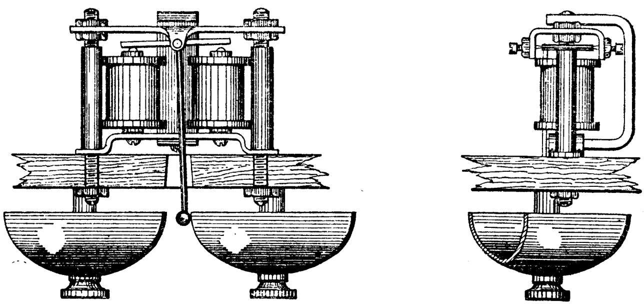

Fig. 13.—Magneto Bell.

induction coil, and the leads necessary to complete this circuit when the apparatus is in use. The station portion of the **secondary** or **line circuit** consists of the secondary winding of the induction coil and the receiver, together with the leads necessary to join these to one another and to the external line. When two receivers are used, they are joined *in parallel.* The station portion of the **signalling circuit** may be divided into that part used to send out a ring and that part used to receive a ring. **Careful consideration of the various circuits and their relation to each other greatly simplifies the tracing of faults.** For example, the case in which it is possible to signal in both directions and to hear speech but not to transmit it, points at once to a disconnection in the primary circuit. It is true that

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a short-circuit in the secondary winding of the induction coil would produce similar results, but this rarely happens.

The lines of a 2-wire circuit are known as the **A and B wires** respectively, and such a circuit is termed metallic to distinguish

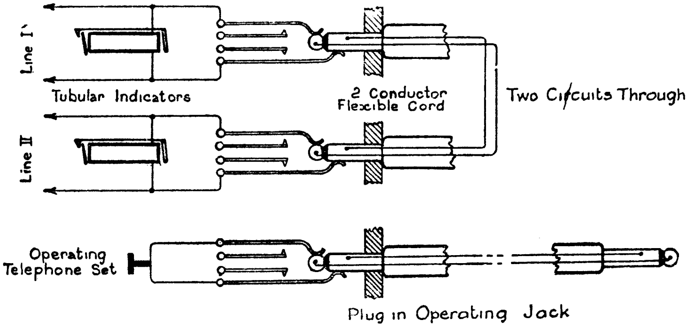

Fig. 14.

it from a single wire circuit in which the earth is used as the return path. In order to prevent overhearing between circuits which run parallel and close to one another, the *A* and *B* wires are, in cables, twisted together, and on open routes, are "revolved together" or crossed at certain intervals, depending on the number of circuits on the route. The result in any of the cases is that an E.M.F. induced in the one wire may be opposed or neutralised by an equal E.M.F. induced in the other wire.*

MAGNETO EXCHANGES

In studying the electrical details of the various telephone switchboards and circuits, the path of the student is easier if he will first make sure that he is familiar with the way in which the apparatus or switchboard is operated.

The simplest case to be dealt with is that in which five or six stations require to be connected to a central switchboard so that any one of them can be spoken to from the central point, and any two can be connected so as to be able to communicate with one another. An indicator is connected across each line which terminates upon a *jack*. These jacks consist of springs shaped somewhat as indicated in Fig. 14. The indicator consists of an iron-clad electromagnet provided with an armature, which, when attracted, permits a tilted hinged shutter to fall forward by its own weight (Fig. 15). A local contact is usually added so that the circuit of an electric bell may be completed, thus giving an audible signal. An extra jack on the switchboard is connected to the telephone used for operating purposes.

* This subject is more fully dealt with in Pamphlets A.1 and H.2.

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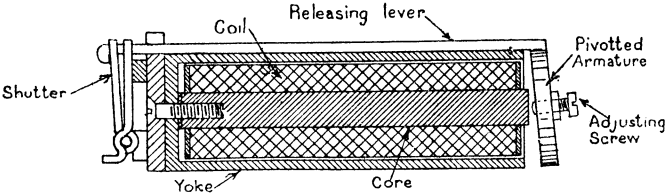

Fig. 15.—Shutter Indicator.

The procedure is that one of the subscribers, by turning the handle of his generator, operates the indicator at the Exchange. The operator, with the aid of a pair of two-way plugs connected together by a two-conductor flexible cord, joins up the operating instrument to the calling line and ascertains which station is required. The operator then connects the operating instrument to the wanted (or called) line and rings that station. Having obtained a reply the operator withdraws the operating plug and connects the two stations by means of a pair of cords. The conversation having finished, the subscribers "ring-off" and both indicators fall. The operator then withdraws the plugs and restoies the indicator to the normal position.

Since the indicators are connected across the circuit whilst conversations are taking place, it is essential that there should be as little magnetic leakage as possible between any two indicators, in order to prevent overhearing between the various circuits. The iron-clad indicator effectually provides this. The only air gap in the magnetic circuit is that between the pole-piece and the armature and between the armature and the soft iron tube which surrounds the windings. The resistance of the indicator is usually 1,000 Ω so as to shunt as little of the speaking current as possible.

Single Cord Board.—Similar facilities are readily arranged by connecting each line to a flexible cord and plug, the indicator being connected between the inner springs at the jack (Fig. 16).

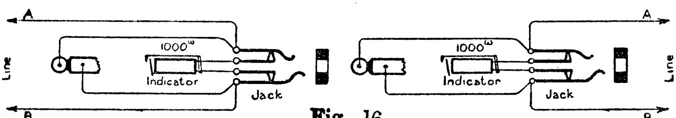

Fig. 16.

The insertion of the plug cuts out the "called" subscriber's indicator, and there is therefore only one indicator across the line. The principal advantage of this board over that previously described is that the calls can be supervised by using the operating plug.

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50 and 100-Line Boards.—When the number of circuits require it, a 50 or a 100-line board is employed. Separate calling and clearing indicators are provided, and keys for ringing and speaking purposes are added. The lines are connected to the long or line springs of 5-point jacks, the inner springs being connected to the calling indicator. For a 50-line board, ten pairs of plugs and cords are fitted. Each pair is provided with a combined ringing and speaking key, which, in one position, connects the operator's speaking apparatus across the cord, and in the other position sends out a ringing current on the calling plug (Fig. 17). The ring-off indicator is of 1,000 Ω tubular type (*i.e.*, shielded to prevent overhearing from magnetic induction); it is in circuit whilst conversations are taking place.

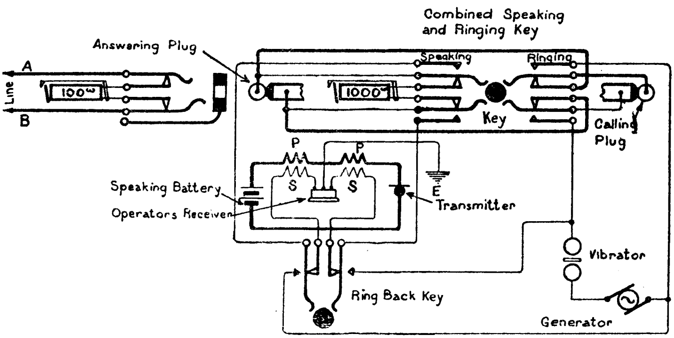

Fig. 17.

The operator's speaking apparatus usually consists of a head-gear receiver and breast-plate transmitter and is connected to the switchboard by a 4-pin plug and flexible cord, the induction coil being located inside the keyboard.

The operations involved in connecting two subscribers together are:—

1. On receipt of the call the operator plugs in with the "answering plug," moves the speaking key to the speaking position, and ascertains the number of the "called" subscriber.

2. The "calling plug" is inserted in the jack of the "called" subscriber and the key is held in the ringing position. A ring is then sent out either by revolving the handle of the switchboard generator or, where the exchange or switchboard is large enough to have warranted the installation of automatic ringing apparatus in the form of a motor generator or ringing vibrator, connection is made between this and the called subscriber's line by holding the key in the ringing position.

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3. The "called" subscriber having answered, the speaking key is placed in the normal position, and this connects the ring-off indicator across the circuit. Should it happen that the calling subscriber has left his telephone, a ring can be given on this plug by putting the speaking key into the speaking position and depressing the ring-back key, which cuts out the operator's speaking apparatus and joins up the generator.

4. The subscribers, having completed their conversation, ring off, and thus project the clearing indicator. The operator then withdraws the plugs and restores the ring-off or clearing indicator to its normal position.

MAGNETO MULTIPLE

Where several hundred subscribers are connected to an exchange, a number of operators are required to attend to the calls. If the subscribers are distributed on, say, six positions, it is necessary to make arrangements by which subscribers on one position may be connected to those upon another. This can be effected by "transfer" circuits between the various switchboards, but the arrangement is cumbrous and slow. The

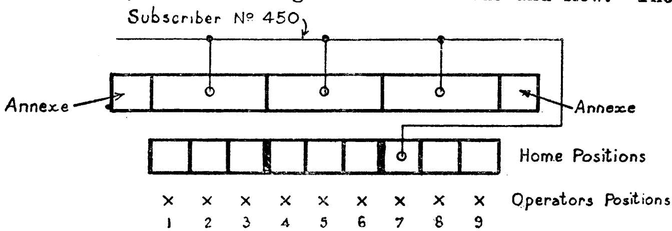

Fig. 18.

difficulty is obviated by "multiplying" the jacks in connection with each subscriber's line at suitable intervals along the switchboard, in such a way that every operator has access to every line connected to the exchange. The principle of this arrangement is illustrated in Fig. 18, where subscriber No. 450 is shown terminating on the seventh operator's position, and connected to the multiple. Operator No. 2 can reach the multiple jacks placed above the operators on either side, but at the beginning and end of the suite of sections the portion of the multiple above operator 3 and that above operator 7 must be repeated, to bring the multiple within the reach of the operators on positions 1 and 9. This addition to the multiple is termed the "annexe."

The multiplying of the subscribers' circuits round the exchange necessitates an *engaged test*. It is possible to connect any given subscriber to other subscribers at each point where the line is repeated on the multiple, and it is, therefore, essential that, a connection having been established, other operators

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requiring this line shall receive an indication that it is already *engaged.* This is accomplished by the third point of the connecting plug, to which a small battery (one pole of which is earthed) is connected. The insertion of the plug in the jack connects this earthed battery to the bushes of that particular subscriber's line throughout the exchange. The wire connecting the barrel of each subscriber's jack is termed the "test wire." Before an operator makes a connection on the multiple she taps the barrel of the wanted or called subscriber's jack with the tip of her plug. If the line is engaged the earthed battery sends a current through one coil of her receiver and induction coil and produces a click. The absence of a click indicates that the subscriber is free.

The earth connections necessary on the operator's telephone must be symmetrical with respect to the two lines of the circuit, and therefore the induction coil is wound in two equal sections, and the earth is applied at the central point of the operator's receiver. In this way the earth connection does not unbalance the line.

The subscriber's circuit is connected to the long springs of the first multiple jack, and passes *viâ* the inner springs to the long springs of the next position of the multiple, and so on until finally it terminates on the line springs of the home position, the "home position" being the position on which the line appears for calling purposes. A multiple arranged in this way is termed a "**series multiple,**" and the fact that the circuits are formed through the contacts of the jacks is indicated by saying that "**break jacks**" are employed. In later systems it will be seen that the line springs of all the multiple jacks for each subscriber's number are joined in parallel, there being very definite objection to the use of a large number of jacks in series.*

CENTRAL BATTERY SIGNALLING (C.B.S.)

There are three C.B.S. systems, known as C.B.S. No. 1, No. 2 and No. 3. The basis of all three systems is a central battery at the exchange for signalling purposes, thereby eliminating the need for a generator at each station, as in the Magneto system. A primary battery is fitted at each station to provide the energy for speech transmission.

The first system introduced, viz., the C.B.S. No. 1 system, operated on a "loop" for calling the exchange and an earth on one line, to give the clearing signal when the receiver is replaced. In this system the act of removing the receiver gives a calling signal at the exchange. The two supervisory indicators on each pair

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* Magneto Exchanges are dealt with more extensively in Pamphlets D.4 and D.5.

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of cords show whether the calling subscriber and the called subscriber have their telephones on the switch-hook or not. On receipt of a call the operator plugs in with the answering plug, and the calling indicator is thereby disconnected from the line. (The supervisory indicator on the answering side of the plug is not affected because the calling subscriber has his receiver off his switch-hook.) Having ascertained the number wanted, the operator plugs in and rings the called subscriber. The supervisory indicator on the called side of the cord is actuated until such time as the subscriber removes his receiver to reply. The conversation having finished, both subscribers replace their receivers, and both the answering and calling supervisory indicators are actuated; the operator then removes the plugs without *entering the circuit to ask if the conversation is finished.* It will therefore be seen that the calling and clearing signals are automatic, as is the case with the Central Battery system.

The subscribers' lines are connected to five-point jacks, the inner springs being joined in series to a 1,000 Ω *doll's-eye indicator* and a 24-volt earthed battery (Fig. 19). This indicator consists

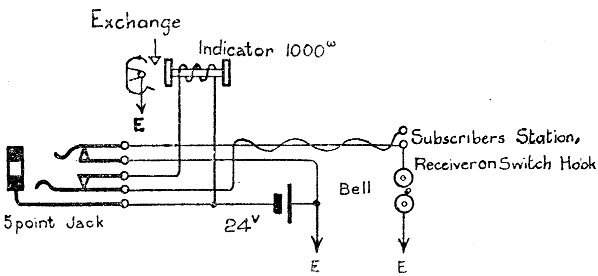

Fig. 19.

of an electromagnet with an armature so shaped that when fully attracted a painted disc is revolved to occupy an aperture in the front part of the strip carrying the indicator.

The subscribers' apparatus is similar to the magneto apparatus already described, but with the generator omitted and the bell normally connected between the *A* line and earth. A current from an earthed generator is sent over the *A* line of the circuit to call the subscriber, whilst the Exchange is called by the subscriber lifting his receiver and looping the *A* and *B* lines of the circuit through his speaking apparatus, thus causing the calling indicator to be actuated (Fig. 19).

The cord circuit is shown in principle in Fig. 20. The two sides of the cord are connected together by condensers. These condensers permit the passage of the ordinary speaking currents,

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but, for direct currents, divide the cords into two parts, thus enabling the two clearing indicators to act independently of each other. The two clearing indicators are of the doll's-eye type, and when plugs are inserted in the jacks the 24-volt earthed battery is connected by the barrel of the jack and shoulder of the plug to the central point of each indicator. During speaking these indicators are unaffected but are operated by the restoration of the receiver to its hook, *viâ* the *A* line and earthed magneto bell of the subscriber's instrument.

For larger exchanges, a C.B.S. multiple board may be used where the provision of the full C.B. equipment cannot

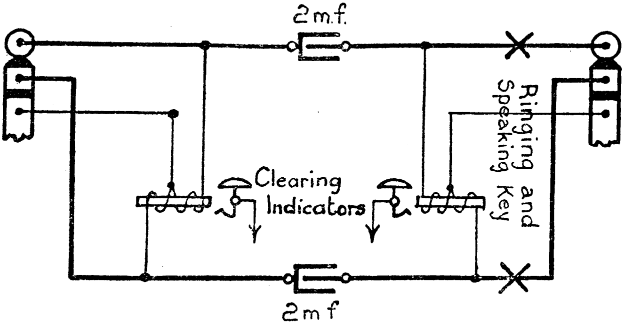

Fig. 20.—Cord Circuit C.B.S. No. 1.

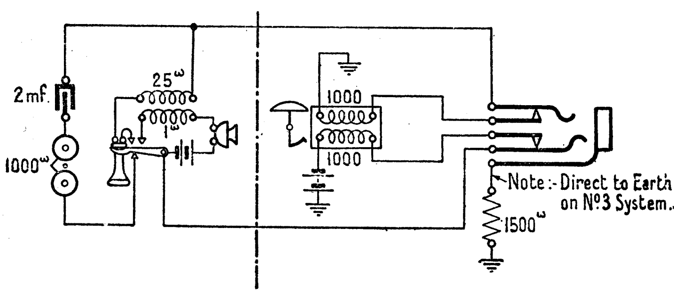

Fig. 20(a).—Subscriber's Circuit C.B.S. No. 2.

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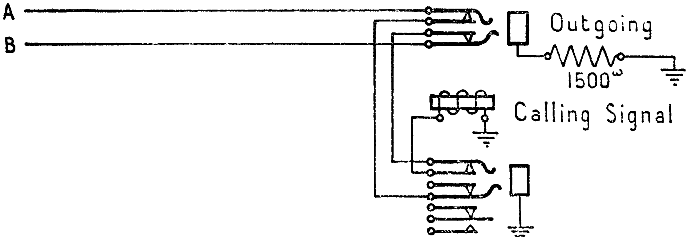

Fig. 20(b).—JUNCTION CIRCUIT C.B.S. No. 2.

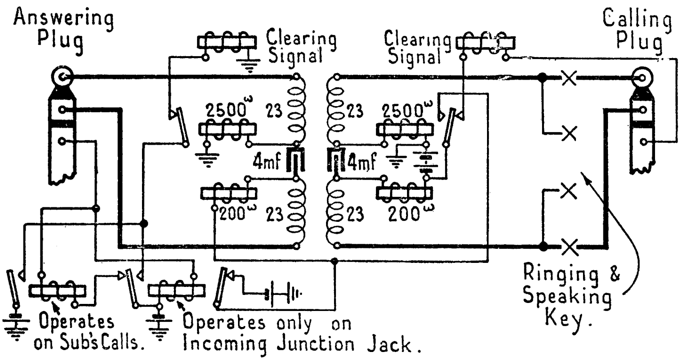

Fig. 20(c).—CORD CIRCUIT C.B.S. No. 2.

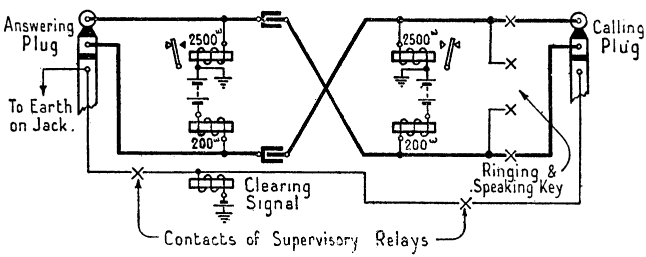

Fig. 20(d).—CORD CIRCUIT C.B.S. No. 3.

be justified on the score of expense. In this arrangement relays and lamps are substituted for the doll's-eye indicators and the switchboard is worked by primary batteries.*

* The C.B.S. System is dealt with more extensively in Pamphlets D.6 and D.7.

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The C.B.S. No. 1 system described above has certain shortcomings, the chief of which are:—

1. Low resistance "earth" connection required at the subscriber's telephone. This increases the cost and difficulty of wiring.

2. The earthed indicator at the exchange, and lack of balance of line insulation may give rise to false signals.

3. The supervisory apparatus is not of maximum efficiency because only half of the number of turns in the windings are operative.

4. The resistance of the subscriber's bell (250 Ω) is included in the total line resistance for clearing signal purposes. This reduces the permissible resistance of the line itself to 750−250 =500 ohms.

In 1923, two new systems, known as C.B.S. No. 2 and C.B.S. No. 3, were introduced with the object of overcoming the aforementioned shortcomings, and at the same time reserving the low current consumption features of the No. 1 system.

The new systems are operated on a "loop" call and "disconnection" clear basis and are, therefore, in these respects similar to the C.B. system, which is described later in this pamphlet.

Units auxiliary apparatus, required for Junction working in the case of C.B.S. No. 1 exchanges, are not required for the C.B.S. No. 2 system, which is suitable for small exchanges where the junction traffic is sufficient to demand regular through signalling, or when junctions carrying calls dialled out by subscribers on automatic exchanges have to be accommodated.

The C.B.S. No. 3 system was intended for small exchanges where the junction traffic did not justify through-signalling, but the circuits have been modified to provide this facility.

It is not suitable for use with a junction to an automatic exchange.

Diagrams relating to these two systems are given in Figs. 20(a), 20(b), 20(c) and 20(d).

Full details will be found in a separate pamphlet devoted to the C.B.S. systems and it will suffice to point out here that calling and clearing conditions are in basic principle the same as in the Central Battery System.

The resistances of the apparatus are as high as possible with a view to limiting the current consumption as much as possible.

CENTRAL BATTERY SYSTEM

The Central Battery System provides for automatic calling and clearing, and dispenses with a speaking battery at the subscriber's premises. The current required for speaking purposes is furnished by a battery common to all the subscribers and situated at the Exchange. At the subscriber's end of the

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circuit a condenser is joined in series with the magneto bell and line. When the receiver is on the switch-hook this condenser prevents the passage of direct current round the line, but not of the alternating current when the Exchange is ringing. The removal of the receiver connects the lines together through the speaking apparatus, and this is employed to complete the circuit of the line relay, and thus to illuminate the calling lamp at the Exchange. Similarly, when the conversation is finished and the receiver is replaced, the stoppage of the current from the Exchange to line causes the corresponding supervisory relay to release its armature and so to light the supervisory lamp.

The connections of the subscribers' instruments and of the cord circuit at the exchange during a conversation are shown diagrammatically in Fig. 21. The 22-volt battery is connected between the centres of the four sets of windings of the repeating

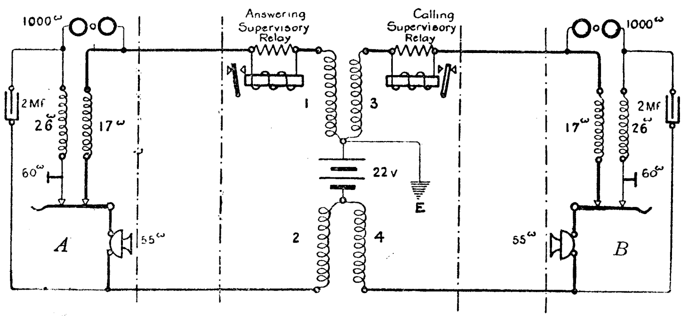

Fig. 21.

coil. This repeating coil consists of a circular ring of fine iron wires, upon which the four windings are disposed. Currents passing round windings 1 and 2 induce similar currents in windings 3 and 4, and in this way speech is transmitted between two sides of the pair of cords.

When the subscriber at *A* raises his receiver, current flows through repeating coil winding No. 1, the 17 Ω primary winding of the induction coil, the transmitter and repeating coil winding No. 2, back to the battery. Variations in the resistance of the transmitter, due to speech, produce current variations in windings 1 and 2, and induce similar current variations in windings 3 and 4, which pass through the subscriber's apparatus at *B* and reproduce the transmitted sounds. Similarly, variations in the resistance of the transmitter at *B* cause current variations to be transmitted through the repeating coil to *A*. The received current passes through the 17 Ω primary and transmitter to the

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B line. This current, in passing through the primary, induces a current in the secondary, which flows through the receiver, transmitter, and condenser back to the secondary. From the junction of the 17 Ω winding of the induction coil and the transmitter, there is, besides the path through the transmitter, another circuit for the receiving current coming from the repeating coil at the exchange. This is *viâ* the receiver, the 26ʷ winding of the induction coil, and the condenser. The portion of the current which tends to pass this way opposes and somewhat weakens the induction effect from the primary to the secondary of the induction coil. The presence of the condenser increases somewhat the current variations (termed the voice currents) when transmitting speech. If the transmitter and receiver were joined in series to the lines without the intervention of the condenser and induction coil, the heavy current flowing would reduce the efficiency of the receiver very seriously, and would render factory adjustment before issue extremely difficult and uncertain.

In Fig. 21, the connections of the subscriber's apparatus are shown in skeleton. When the receiver rests upon the switch-hook, the 1,000 Ω magneto bell and condenser only are connected between the A and B lines; generator rings from the exchange are employed for calling the subscriber, the circuit meanwhile being open (uncompleted) for direct current round the loop. The line relay at the exchange, by means of which the subscriber attracts the attention of the operator when wishing to make a call, is joined in series with the 22-volt battery and the lines, and the raising of the receiver completes the circuit through the subscriber's speaking apparatus, so actuating the line relay and lighting the calling lamp. The insertion of the answering and calling plugs cuts out the line relay of both the calling and called subscribers and establishes the conditions illustrated in Fig. 21.

The supervisory relays, which are connected in circuit with the cords, are heavily shunted by non-inductive resistance. This is because the coils of the supervisory relays have considerable self-inductance, and so offer a good deal of impedance to the passage of speech currents; the non-inductive resistances afford a much easier path for the currents.

It will now be possible to trace the operation of a call.

The removal of the subscriber's receiver completes a circuit of the 22-volt battery through the line relay, the line and the subscriber's speaking apparatus. The line relay, on being energized, lights the calling lamp.

The operator plugs into the jack of the calling line. The 22-volt battery is now connected to the barrel or bush of the

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jack. This at once puts the engaged test on this subscriber's circuit and disconnects the line relay, and the calling lamp therefore ceases to glow. The supervisory relay on the answering side of the pair of cords is energized by the current which passes out through the repeater and subscriber's speaking apparatus; this prevents the lighting of the supervisory or clearing lamp. The operator now places the calling plug in the jack of the called subscriber's line (if disengaged) and rings. The supervisory lamp on the calling plug side glows until it is darkened by the current which flows round the loop as the result of the removal of the called subscriber's receiver. C.B. working may be arranged in a number of different ways, but the consideration of these details will be obtained from the pamphlets dealing with the various systems.*

JUNCTION AND SHORT TRUNK CIRCUITS

Large towns and country areas are usually served by groups of exchanges within the local call fee areas. In order that there may be intercommunication between the exchanges, circuits are provided termed "Junction" Circuits. Circuits to exchanges outside the local call fee area, the distance between which and the terminal exchange is within 25 miles, are termed "Short Trunks." Junctions and Short Trunk Circuits are operated generally in the same manner and the Circuit conditions generally

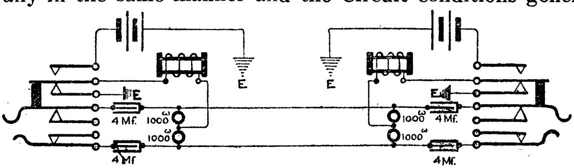

Fig. 22.

apply to both. The term "Trunk Line" is used to denote circuits directly connecting two exchanges, the distance between which exceeds 25 miles.

In the case of a couple of very small exchanges, such as would be served by 50-line magneto boards, the junction circuit may be of the type illustrated in Fig. 22. The circuit terminates upon an 8-point jack at each switchboard, condensers being interposed at each end in order that the currents from the junction signalling battery may not affect subscribers' circuits connected to the junction. A pair of bridging coils is placed across the circuit at each end, and, with the aid of an indicator, battery and the three upper springs of the 8-point jacks, signalling is provided. The insertion of a plug joins up the battery through the indicator used for both calling and clearing to the centre of the bridging coils. The current divides between the two lines of the circuit

* See Pamphlets D.8, 9, 10, 11 and 12.

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and reunites to flow through the indicator at the distant end. In this way the insertion of a plug produces a call at the distant exchange. The distant operator, on plugging in, connects up an opposing battery which neutralises the incoming current, and both indicators return to the normal position. On completion of the conversation the subscribers ring off, thus dropping the cord circuit ring-off indicators. The operator at the end where the call originated withdraws the calling plug from the junction jack, and both junction indicators are actuated until the operator at the other end has withdrawn the answering plug, when both junction clearing signals are restored to normal. A junction circuit of this character would be termed "**both-way ringing junction**" from the fact that the junction circuit is used both for calls to and from each exchange, and that demands for connections are made over the junction circuit itself, as distinct from those junctions in which the request for the connections of a particular subscriber is made by *order wire.*

In large exchanges having multiple switchboards it is essential that each *A* operator (*i.e.*, the operator accepting calls directly from subscribers on the exchange, and controlling the large majority of calls thus originated) shall be able to obtain access to the junction circuits serving the various exchanges in the area. It, therefore, becomes necessary to multiple the junction circuits round the exchange in a similar fashion to that in which the subscribers' circuits are multipled. This junction multiple is placed above the lamps and jacks of subscribers on each home position and beneath the multiple of other subscribers in the exchange. These circuits are termed "**outgoing" junction circuits,** since they are used only for the completion of calls made by subscribers on the home positions to subscribers on other exchanges. The multipled junction terminates at the distant exchange in a cord and plug, thirty of these circuits being allotted to each *B* or "**incoming junction**" operator. With the aid of an engaged test somewhat similar to that used in the case of subscribers' circuits the *A* operator is able to ascertain which junction circuit is disengaged, and by suitable signalling arrangements the insertion of the calling plug in an outgoing junction jack calls the distant exchange, where the operator, on entering the circuit, ascertains the number of the subscriber required.

Where there is a large group of junction circuits between the same exchange this process is slow and cumbrous, and in order to avoid the difficulty a special call wire circuit known as an "**order wire**" is provided between the two exchanges. A key marked with the name of the distant exchange enables each operator to connect her speaking apparatus to this circuit, which terminates at the distant exchange on the speaking apparatus

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of the *B* operator in charge of the incoming end of these junctions.

Requests for connections are passed by the operator depressing the order wire key and giving the number of the wanted subscriber. The operator in charge of the incoming junction circuit sees at once which junction circuits are not in use (since the plugs connected to disengaged circuits are, of course, not inserted in jacks), and then nominates the number of the junction circuit to be used; speaking apparatus is not provided on the incoming junctions themselves in an order wire group.

The signalling arrangements on a junction circuit of this character are such that, taking the case of two C.B. exchanges, the two supervisory lamps at the calling end represent the conditions of the calling and called subscribers at the " home " and distant exchanges respectively. When both these lamps light, the operator at the home position withdraws both plugs. This gives a clearing signal at the incoming end of the junction circuit, and the *B* operator breaks down the connection.

This junction circuit is illustrated only as a typical example of the arrangements necessary. Various complications arise owing to C.B. exchanges having to be connected to C.B.S. or Magneto exchanges. Moreover, ringing junctions and both-way junctions require special treatment. For example, it may happen that in the case of a large exchange, only two junction circuits are justified to a small exchange in the vicinity, and, consequently, order wires are not provided. These junctions are used " both-way," and terminate both on the outgoing junction multiple and on the incoming position, special signalling arrangements being required to ensure the proper use of the circuits.

In some cases arrangements are made whereby the insertion of the incoming junction plug in the subscribers' multiple automatically rings the wanted subscriber without the intervention of the *B* operator, and the clearing or supervisory lamp darkens only when the called subscriber replies.

A large exchange, therefore, consists of a number of *A* positions, on which the subscribers connected to that exchange terminate, and in addition, a number of *B* positions, on which the incoming junction circuits from the various exchanges are terminated. The *B* positions are provided with a subscribers' multiple in the same way as an *A* position, since these operators require to be able to make connection to any subscriber on their exchange. The practical limit to the size of a manual exchange is controlled by the length of the operator's arm, and in practice it is found that 10,000 subscribers represent the limit of the number of subscribers' multiple jacks which can be placed within the reach of each operator.

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TRUNK LINE WORKING

The British Telephone system is divided into zones for the purpose of traffic circulation and control. In each zone, an exchange has been selected to serve as a telephone zone centre, which may be defined as a switching point for long distance traffic to and from exchanges within the zone. Each zone is also sub-divided into groups, each having a Group Centre. Within each group there are exchanges known as minor exchanges, which have direct connexion to the Group Centre. There may also be exchanges known as dependent exchanges, having no direct connexion to the Group Centre, and which are dependent therefore on a minor exchange for the completion of long-distance traffic.

Normally, traffic from one exchange reaches another exchange through its own Group Centre and/or its own Zone Centre. When justified by the volume of traffic, however, direct circuits are provided between any two exchanges, between two Group Centres in the same or different zones, or between a Group Centre in one zone and another Zone Centre.

Previous to the introduction of the " Demand " system, trunks were operated on a " Delay " basis. In the latter system, the "A" operator, on receiving a request for a trunk call, connected the subscriber to a second operator at the zone trunk exchange, where the larger manual exchanges are concerned; in the smaller outlying exchanges the A-operator took particulars of the call from the subscriber and telephoned them to the record operator at the zone trunk exchange.

A typical call on the delay basis is given. Suppose subscriber 150 on Exchange " Y " requires subscriber 1600 on Exchange " Z " in a different area. Subscriber 150 removes his receiver, and his home operator plugs in and receives a request for " trunks." She immediately connects him to a " record circuit " to the trunk Exchange, which terminates in an operator's headset. This operator prepares a ticket giving the number (150) and exchange (" Y ") of the calling subscriber and those of the wanted subscriber (1600, " Z " exchange). The record operator informs the subscriber that he will be rung up later and gives a clearing signal. This connection is then broken down. The ticket is taken to the section on which the trunk line to " Z " is located. The trunk operator deals with these tickets in turn. When the turn of his call arrives the trunk operator obtains subscriber 150 " Y " through a junction circuit to the local exchange. The distant trunk station is then rung by generator current, and the wanted subscriber is there connected to the trunk line. On completion of the conversation, or at the end of the allotted time, the originating trunk operator withdraws the plugs; a clearing signal is automatically given to the distant exchange and to local exchange and the connection is severed.

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The trunk switchboards were of the non-multiple type, providing for termination of the trunk lines on single jacks and calling equipment. The operator's function was to attend to a small group of trunks and to endeavour to pass as many calls represented by tickets, as possible over the lines in her charge. Delay in effecting a trunk connexion always occurred, and varied from 4 or 5 minutes to 15 or more in many cases.

In the " Demand " system, a subscriber making a request for a trunk call is at once connected directly to the trunk operator, who, after taking the particulars from the calling subscriber proceeds to set-up the connexion without releasing the subscriber's line. If direct routing is not available, alternative routing is employed; the operators are provided with routing charts to enable them to ascertain the correct route to any objective exchange. Should it be impossible to complete the connexion quickly, due to the trunk lines or the called subscriber being engaged, the calling subscriber is advised and his connexion released and he is re-rung as soon as the connexion can be set up. Unlike the " delay " method of operating, both zone centres and Group Centres control calls originating within the local areas which they serve. Zone Centres, in addition, function as switching centres for the long-distance calls. As an example, the operating procedure for a typical long-distance trunk call on " demand " working is given in the following paragraph.

A Bideford subscriber demands a call to Thurso and the Bideford operator connects him to Barnstaple, the Group Centre. The Barnstaple operator who is responsible for controlling the call, consults the routing chart and finds that Thurso is in the Wick area. The connexion is extended to the Zone Centre, Bristol, and the operator asks for " Wick ". By means of the routing charts, the Bristol operator determines the correct Zone Centre, Aberdeen, and the information that Aberdeen is obtained *viâ* Glasgow. Should all the Bristol-Glasgow trunks be engaged, an alternative route *viâ* London is used. The Glasgow operator connects the call to Aberdeen and, on request from the Barnstaple operator, the call is extended to Wick. The Barnstaple operator now gives the exchange and number required, and the Wick operator is responsible for calling the Thurso subscriber.

The switchboards are of the multiple type, since it is necessary for all operators to have access to all outgoing lines and a full trunk and junction multiple is therefore provided. Calling equipments are also multiplied in order to distribute incoming traffic to a team of operators, as many as 40 in the larger zone exchanges, and thus permit any one operator devoting as much time as may be necessary to any particular call.

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On calls from a Manual exchange the Trunk operator does not receive a supervisory signal when the subscriber replaces the receiver, because through-signalling is not applied *viâ* the A-position cord circuit.

Because of these conditions, calls from manual exchanges are received on "Record" instead of "Demand" circuits. On receipt of a call on a record circuit, the Trunk operator records the particulars and then reverts the call to the B-operator at the originating exchange, the word "over-plug" being employed, e.g., "Overplug 1234", to inform the B-operator that no notice is to be taken of the engaged test. When the connexion has been established, the Trunk operator removes the plug from the record circuit and, on receipt of the clearing signal, the A-operator clears the connexion. By this means, gravity switch control of supervision is obtained.

At the end of a trunk circuit in a small exchange a combined switch-spring and indicator is employed, as shown in Fig. 23. A current passing through the indicator causes the armature to be attracted and allows the disc of the indicator to fall forward, thus showing that attention is required. The insertion

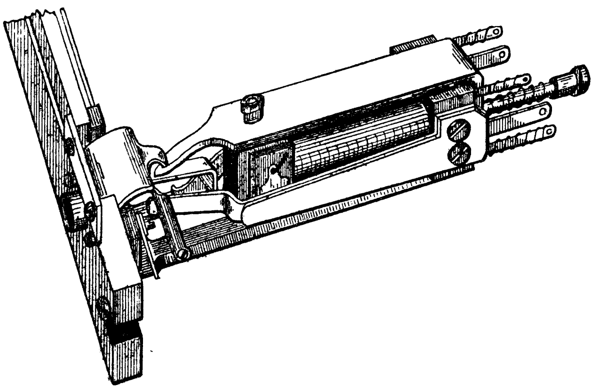

Fig. 23.—Switch Spring Indicator.

of a plug in the jack mechanically restores this disc to its normal position and, at the same time, cuts out the whole of the apparatus connected to the inner springs (Fig. 24). A condenser is placed in series with the indicator, the object being to prevent the passage of steady currents while allowing the alternating ringing current to pass through and actuate the indicator. A 24-volt battery earthed in the centre is connected *viâ* two 200 Ω bridging coils to the inner springs of the jack.

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The function of this arrangement is to provide an automatic clearing signal on withdrawal of the plug. To call this station, the trunk exchange at the other end of the line rings with the generator. On completion of the conversation, the withdrawal

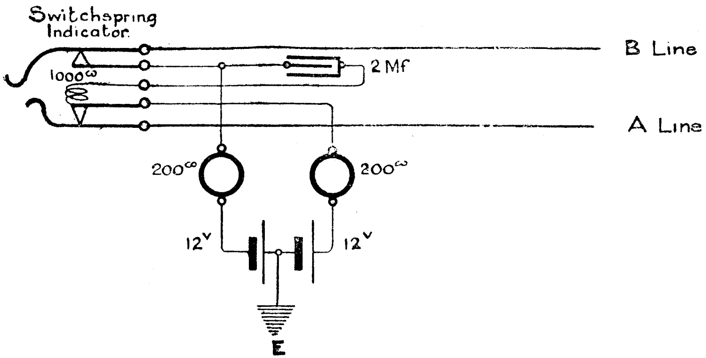

Fig. 24.

of the plug from the jack, and the consequent application to the line (through the inner springs of the jack) of the 24-volt battery, gives a clearing signal on the cord circuit at the trunk exchange at the distant end.

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